

## TOPOLOGICAL SYNTHESIS AND STRUCTURAL ANALYSIS OF PLANAR PARALLEL MECHANISMS

P. VIJAY, A. SRINATH & PARVATINI SRI NAGA VENKAT

*Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation,  
Vaddeswaram, Andhra Pradesh, India*

### ABSTRACT

*This paper presents the identification of the best robot hand for the application of given task at the conceptual stage of design, based on the characteristics of kinematic chains like stiffness and compactness of the structure of the mechanism. The stiffness of the chain mainly depends upon the elasticity, supports and the dimension of the links of the mechanism. The chain with stiffer links will have the greater stiffness and lighter in weight, which leads the designer to think on load bearing capabilities of the chain. Compactness is the structural aspect of the chain, which tells about how closely the links of the chain arranged. More closeness leads to more compactness of the chain structurally, and more compactness leads to difficult in forward kinematics. The methodology adopted already by the Ashok dagar is been used in the present work to identify the best among the nine robot hands (ten bar single degree of freedom) based on the stiffness and compactness. Same characteristics are compared individually, and identified the best and high rated robot hands.*

**KEYWORDS:** *Stiffness, Compactness, Rigidity, Mechanism, Compare & Characteristics*

**Received:** Jan 31, 2019; **Accepted:** Feb 21, 2019; **Published:** Apr 05, 2019; **Paper Id.:** IJMPERDAPR201986

### 1. INTRODUCTION

The classification of robots based on the level of sophistication, whether low or medium and/or high, we have grippers and end-effectors. The gripper consists of mechanism, which can be controlled with servo motors or controlling methods. The gripper is same as that of human hand, which also consists of finger tips for grasping and gripping of the objects. This is how grippers play a vital role in all aspects of robotic applications. Grippers find their application where, hazardous work environments like handling radioactive materials, welding with high temperature zones, special applications etc. The usage of the grippers may differ from geometry to geometry of the objects. As per the requirement of the objects, the design of robot hand gripper may vary. The main limitations of the robot hand grippers which we need to focus are difficulty in manipulation and stability of different irregular objects. In the history, many of the robot hands are there with multi number degree of freedom and controlling of this very much complex.

### 2. LITERATURE SURVEY

Based on the topology the kinematic chains and their characteristics can be read by the designer at the conceptual design stage, and can able to select the best mechanism to do the further work as per the application [1]. Ashok dargar modelled the kinematic chains as springs which are connected in series and obtained the characteristics as compactness and stiffness [2]. The performance of the kinematic chains was evaluated based on

the proposed concept of correlation by A. Srinath and Rao[3]. A. C. Rao presented the different kinematic inversions using fuzzy logics [4]. A. C. Rao presented the work of selecting the best kinematic chain at the design stage by the proposed methodology of comparative study of chains and mechanisms using kinematic characteristics like stiffness and compactness of the mechanism, and has given logical aspects of weakness and strength of the chain/mechanism structurally to obtain the mechanical advantages of the chains/mechanisms. As a designer, one must know the ability of static behaviour of the chain/mechanism in transferring the force or torque. A chain, in which the links are connected close to each other resemble the compactness of the chain or mechanism. In the graph theory, the distance between the two links in the mechanism is equal to the least number of joints that separate them. This is how the compactness of the each mechanism is calculated. Now, the stiffness is the other characteristic considered and calculated. Stiffness depends on links stiffness and elasticity of the links[5]. A. C. Rao proposed another methodology for topological characteristics based on genetic algorithm [6]. Hong-Sen Yan and Chin-Hsing Kuo have focussed their attention in representing the kinematic characteristics of the mechanisms and their analysis of variable kinematic joints. The proposed work results the logical foundation of structural analysis of mechanisms with topological characteristics.[7] P. Vijay applied proposed methodology and rated the best mechanism at the design stage itself for nine ten bar mechanisms of single degree of freedom based on the joint matrix and chain value matrix like characteristics [8]. Shinji Nishiwaki proposed methodology based on topology of optimal structure for homogenation and flexibility applied to mechanisms[9]. QiongJin and Ting-Li Yang proposed a methodology for topology synthesis of parallel manipulators based actuation, built in it. The matrices of output and input characteristics result in formulating the formula for mobility equation and output character equation.

### 3. OBJECTIVE OF THE WORK

The main objective of this work is to model the nine single degree of freedom, ten bar mechanism with the springs as the link forming closed kinematic chain, for which the topological characteristics such as stiffness and compactness for each mechanism are calculated by the application of proposed methodology by Ashok dargar [1] and are compared, and to rate the best mechanism to be suited for optimally converting the given input to the required output. The stiffness and compactness are formulated in terms of stiffness and distances matrices. The links of the mechanism are stiffer, then such mechanism is stiffer leads to less weight and more elastic and more flexible. The compactness resembling as more closely, the links are connected then, the mechanism is more compact and occupies less space. Based on these, the mechanisms are compared and are rated as more stiffer and high compactness.

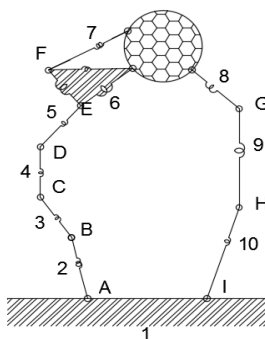


Figure 1: Robot Hand (a)

#### 4. STRUCTURAL SYNTHESIS AND ANALYSIS

The chain is modelled like a system of springs connected in series; the stiffness of the chain can be calculated as the summation of the joint values  $j_v$ . [1]

$$\text{The joint values } j_v = \frac{\text{Summation of degree of links connected}}{\text{Number of links connected at that joint}}$$

The stiffness of the chain can be calculated as,

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_n$$

For robot hand Figure 1 (a)

$$\begin{aligned} 1/k &= 1/k_1 + 1/k_2 + \dots + 1/k_{10} \\ &= 1/4 + 1/4 + 1/4 + 1/4 + 1/4.5 + 1/5 + 1/2.5 + 1/2 + 1/4 + 1/4 \\ &= 2.82 \end{aligned}$$

The distance between two links is nothing but the least number of joints that separate them and the distance between two joints is least number of links that separate them. [1]

Two distant matrices are calculated as D1 – link distance matrix and D2 – joint distance matrix and the link distance value and joint distance value are nothing but sum of all elements of D1 and D2 values respectively. The D1 values are taken from the previous work of the author [7] for all the nine robot hands. Now the D2 for robot hand 1(a) can be computed as follows:

$$D2 = \begin{bmatrix} 0 & 1 & 2 & 3 & 4 & 5 & 3 & 2 & 1 \\ 1 & 0 & 1 & 2 & 3 & 4 & 4 & 3 & 2 \\ 2 & 1 & 0 & 1 & 2 & 3 & 5 & 4 & 3 \\ 3 & 2 & 1 & 0 & 1 & 2 & 6 & 5 & 4 \\ 4 & 3 & 2 & 1 & 0 & 1 & 7 & 6 & 5 \\ 5 & 4 & 3 & 2 & 1 & 0 & 8 & 7 & 6 \\ 3 & 4 & 5 & 6 & 7 & 8 & 0 & 1 & 2 \\ 2 & 3 & 4 & 5 & 6 & 7 & 1 & 0 & 1 \\ 1 & 2 & 3 & 4 & 5 & 6 & 2 & 1 & 0 \end{bmatrix}$$

For robot hand (a),

Joint distance value, J. D. V = sum of all values of D2 matrix

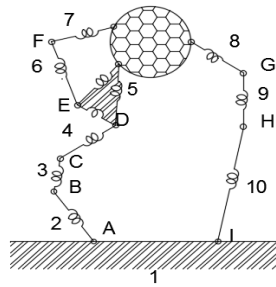
$$= 240$$

Link distance value, L. D. V = 329 [7]

Compactness C, = J. D. V + L. D. V

$$= 569$$

Similarly, the stiffness and compactness can be computed for other robot hands as follows:



**Figure 2: Robot Hand (b)**

The chain is modelled like a system of springs connected in series; the stiffness of the chain can be calculated as the summation of the joint values  $j_v$ . [1]

$$\text{The joint values } j_v = \frac{\text{Summation of degree of links connected}}{\text{Number of links connected at that joint}}$$

The stiffness of the chain can be calculated as,

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_n$$

For robot hand Figure 1 (b)

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_{10}$$

$$= 1/4 + 1/4 + 1/4 + 1/4.5 + 1/5 + 1/4.5 + 1/2 + 1/2 + 1/4 + 1/4$$

$$= 2.89$$

The distance between two links is nothing but the least number of joints that separate them, and the distance between two joints is least number of links that separate them. [1]

Two distant matrices are calculated as D1 – link distance matrix and D2 –joint distance matrix and the link distance value and joint distance vale are nothing but sum of all elements of D1 and D2 values, respectively [10-13]. The D1 values are taken from the previous work of the author [7] for all the nine robot hands. Now, the D2 for robot hand (b) can be computed as follows:

	0	1	2	3	4	5	3	2	1
	1	0	1	2	3	4	4	3	2
	2	1	0	1	2	3	5	4	3
	3	2	1	0	1	2	6	5	4
D2=	4	3	2	1	0	1	7	6	5
	5	4	3	2	1	0	8	7	6
	3	4	5	6	7	8	0	8	2
	2	3	4	5	6	7	1	0	1
	1	2	3	4	5	6	2	1	0

For robot hand (b),

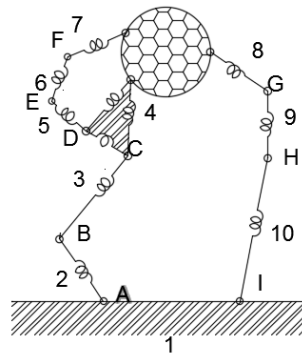
Joint distance value, J. D. V = sum of all values of D2 matrix

=249

Link distance value, L. D. V= 332[7]

Compactness C,  $= J. D. V + L. D. V$

$=581$



**Figure 3: Robot Hand(c)**

	0	1	2	3	4	5	3	2	1
	1	0	1	2	3	4	4	3	2
	2	1	0	1	2	3	5	4	3
	3	2	1	0	1	2	6	5	4
D2=	4	3	2	1	0	1	7	6	5
	5	4	3	2	1	0	8	7	6
	3	4	5	6	7	8	0	1	2
	2	3	4	5	6	7	1	0	1
	1	2	3	4	5	6	2	1	0

For robot hand (c),

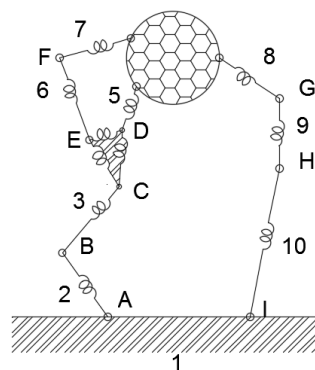
Joint distance value, J. D. V = sum of all values of D2 matrix

$$\equiv 240$$

Link distance value, L. D. V= 332[7]

Compactness C,                      = J. D. V+L. D. V

$$=572$$



**Figure 4: Robot Hand (d)**

The chain is modelled like a system of springs connected in series; the stiffness of the chain can be calculated as the summation of the joint values  $j_{v, [1]}$

$$\text{The joint values } j_v = \frac{\text{Summation of degree of links connected}}{\text{Number of links connected at that joint}}$$

The stiffness of the chain can be calculated as,

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_n$$

For robot hand Figure 4 (d)

$$\begin{aligned} 1/k &= 1/k_1 + 1/k_2 + \dots + 1/k_{10} \\ &= 1/4 + 1/4 + 1/4 + 1/4.5 + 1/7.5 + 1/2.5 + 1/2.5 + 1/2 + 1/4 + 1/4 \\ &= 2.9 \end{aligned}$$

The distance between two links is nothing but the least number of joints that separate them and the distance between two joints is least number of links that separate them. [1]

Two distant matrices are calculated as D1 – link distance matrix and D2 –joint distance matrix and the link distance value and joint distance value are nothing but sum of all elements of D1 and D2 values, respectively. The D1 values are taken from the previous work of the author [7] for all the nine robot hands. Now, the D2 for robot hand (d) can be computed as follows:

	0	1	2	3	4	4	3	2	1
	1	0	1	2	3	3	4	3	2
	2	1	0	1	2	2	5	4	3
	3	2	1	0	1	1	6	5	4
D2=	4	3	2	1	0	2	7	6	5
	4	3	2	1	2	0	7	6	5
	3	4	5	6	7	7	0	1	2
	2	3	4	5	6	6	1	0	1
	1	2	3	4	5	5	2	1	0

For robot hand (d),

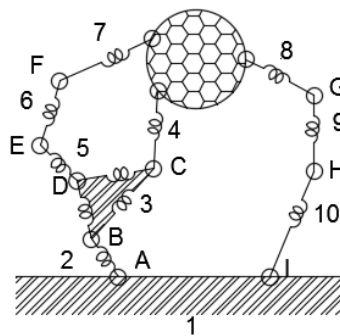
Joint distance value, J. D. V = sum of all values of D2 matrix

$$=228$$

Link distance value, L. D. V= 330[7]

Compactness C, = J. D. V+L. D. V

$$=558$$



**Figure 5: Robot Hand(e)**

The chain is modelled like a system of springs connected in series; the stiffness of the chain can be calculated as the summation of the joint values  $j_v$ . [1]

$$\text{The joint values } j_v = \frac{\text{Summation of degree of links connected}}{\text{Number of links connected at that joint}}$$

The stiffness of the chain can be calculated as,

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_n$$

For robot hand Figure 5 (e)

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_{10}$$

$$= 1/4 + 1/4 + 1/4.5 + 1/7.5 + 1/2.5 + 1/4.5 + 1/2 + 1/2 + 1/4 + 1/4$$

$$= 2.97$$

The distance between two links is nothing but the least number of joints that separate them, and the distance between two joints is least number of links that separate them. [1]

Two distant matrices are calculated as D1 – link distance matrix and D2 –joint distance matrix and the link distance value and joint distance value are nothing but sum of all elements of D1 and D2 values, respectively. The D1 values are taken from the previous work of the author [7] for all the nine robot hands. Now, the D2 for robot hand (e) can be computed as follows:

$$D2 = \begin{bmatrix} 0 & 1 & 2 & 3 & 3 & 4 & 3 & 2 & 1 \\ 1 & 0 & 1 & 2 & 2 & 3 & 4 & 3 & 2 \\ 2 & 1 & 0 & 1 & 1 & 2 & 5 & 4 & 3 \\ 3 & 2 & 1 & 0 & 2 & 3 & 6 & 5 & 4 \\ 3 & 2 & 1 & 2 & 0 & 1 & 6 & 5 & 4 \\ 4 & 3 & 2 & 3 & 1 & 0 & 7 & 6 & 5 \\ 3 & 4 & 5 & 6 & 6 & 7 & 0 & 1 & 2 \\ 2 & 3 & 4 & 5 & 5 & 6 & 1 & 0 & 1 \\ 1 & 2 & 3 & 4 & 4 & 5 & 2 & 1 & 0 \end{bmatrix}$$

For robot hand (e),

Joint distance value, J. D. V = sum of all values of D2 matrix

$$= 217$$

Link distance value, L. D. V = 330[7]

Compactness C, = J. D. V + L. D. V

$$= 547$$

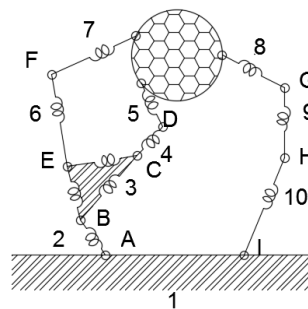


Figure 6: Robot Hand (f)



The chain is modelled like a system of springs connected in series; the stiffness of the chain can be calculated as the summation of the joint values  $j_v$ . [1]

$$\text{The joint values } j_v = \frac{\text{Summation of degree of links connected}}{\text{Number of links connected at that joint}}$$

The stiffness of the chain can be calculated as,

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_n$$

For robot hand Figure 6 (f)

$$\begin{aligned} 1/k &= 1/k_1 + 1/k_2 + \dots + 1/k_{10} \\ &= 1/4 + 1/4.5 + 1/7.5 + 1/2.5 + 1/4.5 + 1/4 + 1/2 + 1/2 + 1/4 + 1/4 \\ &= 2.97 \end{aligned}$$

The distance between two links is nothing but the least number of joints that separate them, and the distance between two joints is least number of links that separate them. [1]

Two distant matrices are calculated as D1 – link distance matrix and D2 – joint distance matrix and the link distance value and joint distance value are nothing but sum of all elements of D1 and D2 values, respectively. The D1 values are taken from the previous work of the author [7] for all the nine robot hands. Now, the D2 for robot hand (f) can be computed as follows:

$$D2 = \begin{bmatrix} 0 & 1 & 2 & 2 & 3 & 4 & 3 & 2 & 1 \\ 1 & 0 & 1 & 1 & 2 & 3 & 4 & 3 & 2 \\ 2 & 1 & 0 & 1 & 2 & 3 & 5 & 4 & 3 \\ 2 & 1 & 1 & 0 & 1 & 2 & 5 & 4 & 3 \\ 3 & 2 & 2 & 1 & 0 & 1 & 6 & 5 & 4 \\ 4 & 3 & 3 & 2 & 1 & 0 & 7 & 6 & 5 \\ 3 & 4 & 5 & 5 & 6 & 7 & 0 & 1 & 2 \\ 2 & 3 & 4 & 4 & 5 & 6 & 1 & 0 & 1 \\ 1 & 2 & 3 & 3 & 4 & 5 & 2 & 1 & 0 \end{bmatrix}$$

For robot hand (f),

Joint distance value, J. D. V = sum of all values of D2 matrix

$$= 220$$

Link distance value, L. D. V = 332 [7]

Compactness C, = J. D. V + L. D. V

$$= 552$$

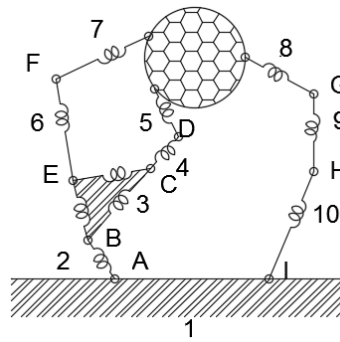


Figure 7: Robot Hand (g)

The chain is modelled like a system of springs connected in series; the stiffness of the chain can be calculated as the summation of the joint values  $j_v$ . [1]

$$\text{The joint values } j_v = \frac{\text{Summation of degree of links connected}}{\text{Number of links connected at that joint}}$$

The stiffness of the chain can be calculated as,

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_n$$

For robot hand Figure 7 (g)

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_{10}$$

$$= 1/4 + 1/4.5 + 1/7.5 + 1/4.5 + 1/2 + 1/4.5 + 1/2 + 1/2 + 1/4 + 1/4$$

$$= 3.04$$

The distance between two links is nothing but the least number of joints that separate them and the distance between two joints is least number of links that separate them. [1]

Two distant matrices are calculated as D1 – link distance matrix and D2 –joint distance matrix and the link distance value and joint distance vale are nothing but sum of all elements of D1 and D2 values, respectively. The D1 values are taken from the previous work of the author [7] for all the nine robot hands. Now, the D2 for robot hand (g) can be computed as follows:

$$D2 = \begin{bmatrix} 0 & 1 & 2 & 3 & 2 & 3 & 3 & 2 & 1 \\ 1 & 0 & 1 & 2 & 1 & 2 & 4 & 3 & 2 \\ 2 & 1 & 0 & 1 & 2 & 2 & 5 & 4 & 3 \\ 3 & 2 & 1 & 0 & 3 & 3 & 6 & 5 & 4 \\ 4 & 1 & 1 & 2 & 0 & 1 & 5 & 4 & 3 \\ 3 & 2 & 2 & 3 & 1 & 0 & 6 & 5 & 4 \\ 3 & 4 & 5 & 6 & 5 & 6 & 0 & 1 & 2 \\ 2 & 3 & 4 & 5 & 4 & 5 & 1 & 0 & 1 \\ 1 & 2 & 3 & 4 & 3 & 4 & 2 & 1 & 0 \end{bmatrix}$$

For robot hand (g),

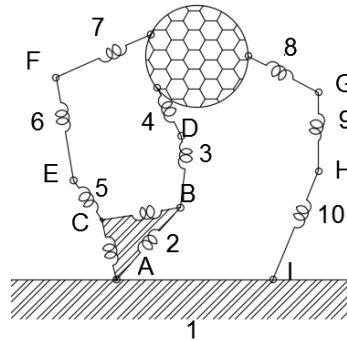
Joint distance value, J. D. V = sum of all values of D2 matrix

$$=201$$

Link distance value, L. D. V= 316[7]

Compactness C, = J. D. V+L. D. V

$$=517$$



**Figure 8: Robot Hand (h)**

The chain is modelled like a system of springs connected in series; the stiffness of the chain can be calculated as the summation of the joint values  $j_v$ . [1]

$$\text{The joint values } j_v = \frac{\text{Summation of degree of links connected}}{\text{Number of links connected at that joint}}$$

The stiffness of the chain can be calculated as,

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_n$$

For robot hand Figure 4 (d)

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_{10}$$

$$= 1/4.5 + 1/7.5 + 1/4.5 + 1/2 + 1/4.5 + 1/4 + 1/2 + 1/2 + 1/4 + 1/4$$

$$= 3.04$$

The distance between two links is nothing but the least number of joints that separate them, and the distance between two joints is least number of links that separate them. [1]

Two distant matrices are calculated as D1 – link distance matrix and D2 – joint distance matrix and the link distance value and joint distance value are nothing but sum of all elements of D1 and D2 values, respectively. The D1 values are taken from the previous work of the author [7] for all the nine robot hands. Now, the D2 for robot hand (i) can be computed as follows:

	0	1	2	1	2	3	4	3	2
	1	0	1	2	3	4	5	4	3
	2	1	0	3	4	5	6	5	4
	1	2	3	0	1	2	3	2	1
D2=	2	3	4	1	0	1	4	3	2
	3	4	5	2	1	0	5	4	3
	4	5	6	3	4	5	0	1	2
	3	4	5	2	3	4	1	0	1
	2	3	4	1	2	3	2	1	0

For robot hand (i),

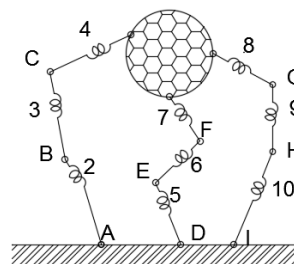
Joint distance value, J. D. V = sum of all values of D2 matrix

$$=194$$

Link distance value, L. D. V = 313[7]

Compactness C, = J. D. V+L. D. V

$$=507$$



**Figure 9: Robot Hand (i)**

The chain is modelled like a system of springs connected in series; the stiffness of the chain can be calculated as the summation of the joint values  $j_v$ . [1]

$$\text{The joint values } j_v = \frac{\text{Summation of degree of links connected}}{\text{Number of links connected at that joint}}$$

The stiffness of the chain can be calculated as,

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_n$$

For robot hand Figure 4 (d)

$$1/k = 1/k_1 + 1/k_2 + \dots + 1/k_{10}$$

$$= 1/6 + 1/4 + 1/4 + 1/2 + 1/4 + 1/4 + 1/2 + 1/2 + 1/4 + 1/4$$

$$= 3.16$$

The distance between two links is nothing but the least number of joints that separate them, and the distance between two joints is least number of links that separate them. [1]

Two distant matrices are calculated as D1 – link distance matrix and D2 –joint distance matrix and the link distance value and joint distance value are nothing but sum of all elements of D1 and D2 values, respectively. The D1 values are taken from the previous work of the author [7] for all the nine robot hands. Now, the D2 for robot hand 8(h) can be computed as follows:

$$D2 = \begin{bmatrix} 0 & 1 & 1 & 2 & 3 & 3 & 3 & 2 & 1 \\ 1 & 0 & 2 & 1 & 2 & 3 & 4 & 3 & 2 \\ 1 & 1 & 0 & 2 & 1 & 2 & 4 & 3 & 2 \\ 2 & 1 & 2 & 0 & 3 & 4 & 5 & 4 & 3 \\ 2 & 2 & 1 & 3 & 0 & 1 & 5 & 4 & 3 \\ 3 & 3 & 2 & 4 & 1 & 0 & 6 & 5 & 4 \\ 3 & 4 & 4 & 5 & 5 & 6 & 0 & 1 & 2 \\ 2 & 3 & 3 & 4 & 4 & 5 & 1 & 0 & 1 \\ 1 & 2 & 2 & 3 & 3 & 4 & 2 & 1 & 0 \end{bmatrix}$$

For robot hand (h),

Joint distance value, J. D. V = sum of all values of D2 matrix

$$=200$$

Link distance value, L. D. V = 300[7]

Compactness C, = J. D. V+L. D. V

$$=500$$

## 5. RESULTS AND DISCUSSIONS

The table gives the mechanisms with the stiffness values and compactness values, D1 and D2 distant matrices and robot hands (a) to (i). The rating of robot hands were done as per the stiffness value and based on the compactness value. The links are stiffer than the robot hand that is more rigid, and the links are closer, and more is the compactness i. e. structurally rigid.

## 6. CONCLUSIONS

A simple method to compute the stiffness of the mechanisms and compactness of the mechanism is applied successfully, for ten bar single degree of freedom of such nine robot hands, and are rated by comparing the stiffness and compactness. The stiffness and compactness will be more for the robot hands, whose value is low [1]. Out of the nine robot hands, robot hand (a) is stiffer having stiffness value 2.82, and robot hand (i) is more compact or rigid, having compactness value 500.

**Table 1: Robot Hands with Compactness Values**

Robot Hand	D1	D2	Compactness
i	200	300	500
h	194	313	507
g	201	316	517
e	217	330	547
f	220	332	552
d	228	330	558

Table 1: Contd.,			
a	240	329	569
c	240	332	572
b	249	332	581

Table 2: Robot Hands with Stiffness Values

Robot hand	Stiffness
a	2.82
b	2.89
d	2.9
c	2.92
e	2.97
f	2.97
g	3.04
h	3.04
i	3.16

Table 3: Robot Hands Rating based on Compactness Values

Robot hand	D1	D2	Compact	Rated high/low
i	200	300	500	1
h	194	313	507	2
g	201	316	517	3
e	217	330	547	4
f	220	332	552	5
d	228	330	558	6
a	240	329	569	7
c	240	332	572	8
b	249	332	581	9

Table 4: Robot Hands Rating based on Stiffness Values

Robot hand	Stiffness	Rated high/low
a	2.82	1
b	2.89	2
d	2.9	3
c	2.92	4
e	2.97	5
f	2.97	5
g	3.04	6
h	3.04	6
i	3.16	7

## REFERENCES

1. Ashok Dargar, *Topological Characteristics of Planar Linkage Including Platform Type Robots* (Universal Journal of Mechanical Engineering 2(3): 83-86, 2014)
2. Srinath, A. C. Rao, 'Correlation to detect isomorphism, parallelism and type of Freedom' *Mech. Mach. Theory* 41, 646-655, (2006):
3. C. Rao, 'Application of fuzzy logic for the study of isomorphism, inversions, symmetry, parallelism and mobility in kinematic chains' *Mech. Mach. Theory* 35, 1103-1116, (2000).
4. C. Rao, 'Topological characteristics of linkage mechanisms with particular reference to platform' *Mech. Mach. Theory*, 30 (1), 30-39, (1995).

5. C. Rao, 'A genetic algorithm for topological characteristics of kinematic Chains' *ASME J. Mech. Des.* 122, 228-231, (2000).
6. Hong-Sen Yan and Chin-HosingKuo, 'Topological Representations and Characteristics of Variable Kinematic Joints' *Journal of Mechanical Design*, 128(2), 384-391 (Jun 17, 2005)
7. Bhuvaneswari, K., & Ezhilarasi, A. On Nano Semi-Generalised And Nano Generalised-Semi Closed Sets In Nano Topological Spaces.
8. P. Vijay, 'Design, analysis and selection of planar parallel mechanisms' *International Journal of Engineering & Technology*, 7 (2.32) 44-48 (2018)
9. Shinji Nishiwaki, 'topology optimization of compliant mechanisms using the homogenization method' *international journal for numerical methods in engineering Int. J. Numer. Meth. Engng.* 42, 535—559 (1998).
10. QiongJin and Ting-Li Yang, 'Theory for Topology Synthesis of Parallel Manipulators and Its Application to Three-Dimension-Translation Parallel Manipulators' *J. Mech. Des.* 126(4), 625-639 (Aug 12, 2004)
11. Kishore Kumar, K., Srinath, A., Sri Naga Venkat, P., Harish, M. Simulation of delta parallel manipulator for medical applications (2017) *Journal of Advanced Research in Dynamical and Control Systems*, 9 (Special Issue 18), pp. 1810-1817
12. Vijay, P., Srinath, A., Venkat, P. S. N., Ranganath, L., Appalaraju, P. Design, analysis and selection of planar parallel mechanisms (2018) *International Journal of Engineering and Technology(UAE)*, 7 (2), pp. 44-48.
13. Kumar, G. N. S. and A. Srinath. 2018. "An Ergonomical condition's of Pedestrians on Accelerating Moving Walkway: A People Mover System." *International Journal of Mechanical and Production Engineering Research and Development* 8 (Special Issue 7): 1376-1381. [www.scopus.com](http://www.scopus.com).
14. Kumar, Gurram Narendra Santosh, and A. Srinath. "Exploration of Accelerating Moving Walkway for Futuristic Transport System in Congested and Traffical Areas." (2018): 616-624.
15. Mallik, K. S. K., Kumar, G. N. S., Balasubramanyam, S., Swetha, D. A review on preparation and structural characterization studies of graphitic carbon nitride (2017) *Journal of Advanced Research in Dynamical and Control Systems*, 9 (Special Issue 14), pp. 1869-1880

